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MICROBAROGRAPH STUDIES

by

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I Introduction

This is the first annual report of the atmospheric wave studies project at the Stanford Geophysics Department. The principal objective is to understand atmospheric pressure fluctuations in the period range 1 - 15 minutes. At present we cannot explain most of the observed variation at Stanford. Next year when we have three instruments installed it is likely that we will be able to ascribe much of the fluctuation to jet stream instabilities. This has been the case for data recorded in Boston (Madden and Claerbout) and New York (Tolstoy), however the jet stream is much farther south in the western U. S. and we will not pre-judge this matter.

During the past year there have been atmospheric nuclear explosions set off in China and the South Pacific (by the French). The South Pacific explosions were too weak and far away to be recorded on our microphone. These explosions offer a unique situation for atmospheric studies. The sound waves emitted from such an explosion sample winds and temperatures at altitudes, latitudes and longitudes which are inaccessible to conventional meteorological observation. The theoretical section of this report represents an attempt to develop a means of simulating the wave's propagation about the earth.

II Antipodal Focus on an Irregular Earth

The sound waves emitted from nuclear explosions, exploding volcanos, and great earthquakes have been observed to propagate more than once around the earth. For example, Wexler and Hess (1962, Global Atmospheric Pressure Effects of the October 30, 1961, Explosion, Journal of Geophysical Research, v. 67, n. 10, p. 3875-3887) summarize data from around the world for an explosion in Siberia. The disturbance seen at the antipodal point is of special interest because from an over idealized point of view one expects that this disturbance could reach a magnitude comparable to the magnitude at the source. Besides the obvious need to account for dissipative effects, observations indicate the extreme importance of horizontal atmospheric variations in defocusing the antipodal focus. See the highly irregular arrival time maps in figures 1 to 3. By looking at the U. S. one realizes that complexity increases with the density of observation.

There has been much theoretical work on global air waves in the 1960's but it seems that perhaps none of it has addressed itself to the horizontal atmospheric variations which are so apparent in these observations. Our objective in this study is to develop a feasible mathematical-computational scheme for quantitative description of these phenomena. We would hope to be able to answer such questions as: Which is more important, temperature variations or wind variations? From observation of the waves may we deduce any

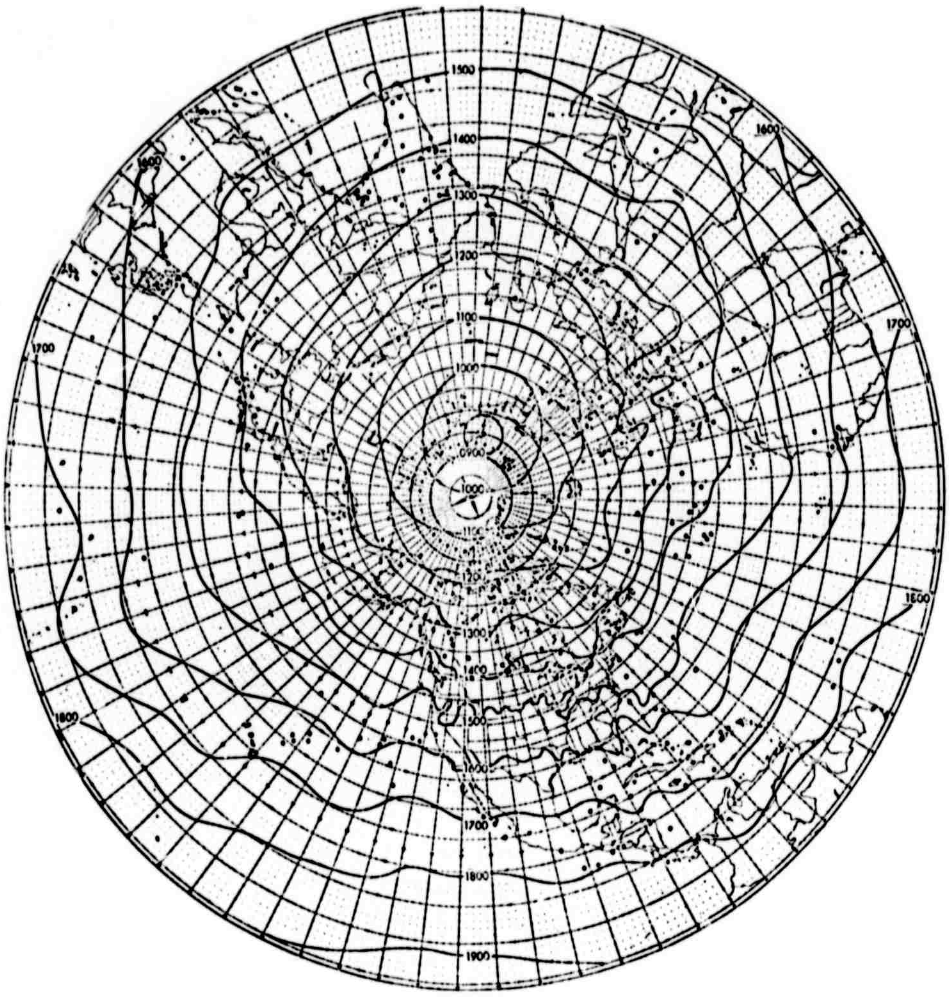


Figure 1: Arrival time of primary wave over the northern hemisphere, (from Wexler and Hass).

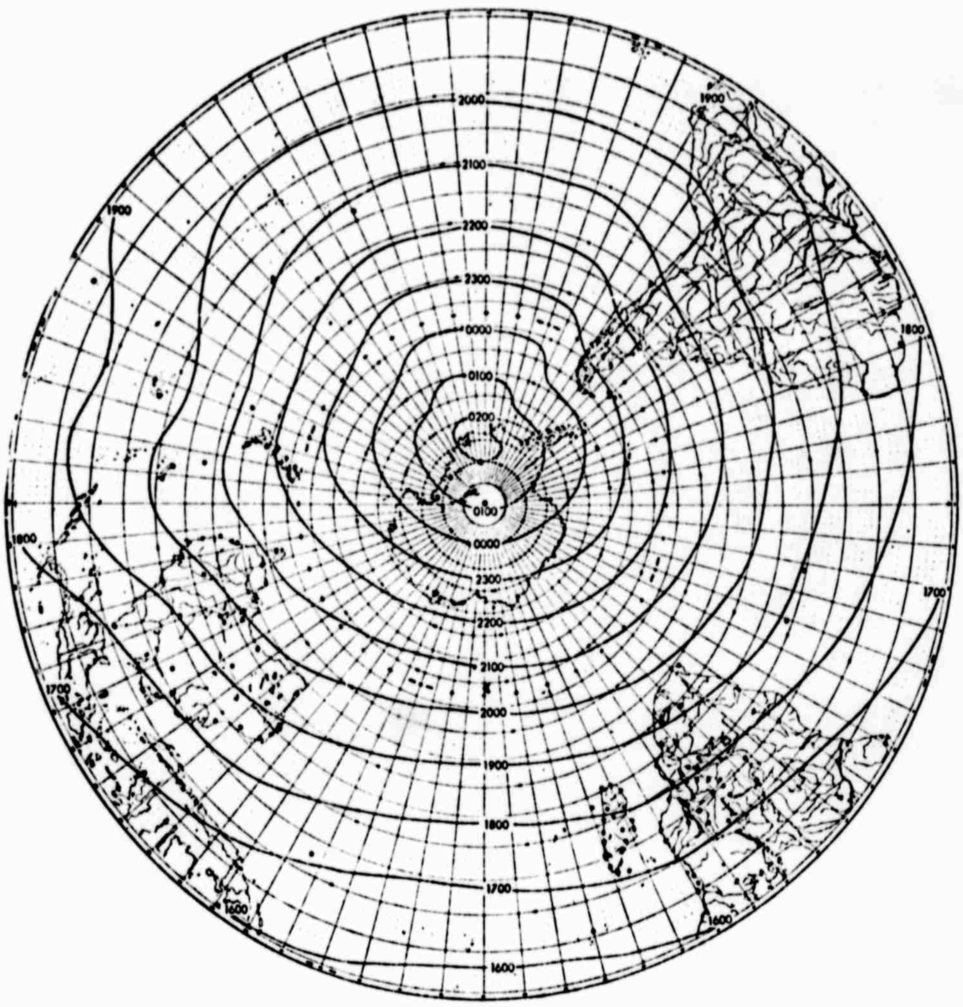


Figure 2: Arrival time of the primary wave over the southern hemisphere (from Wexler and Hass)

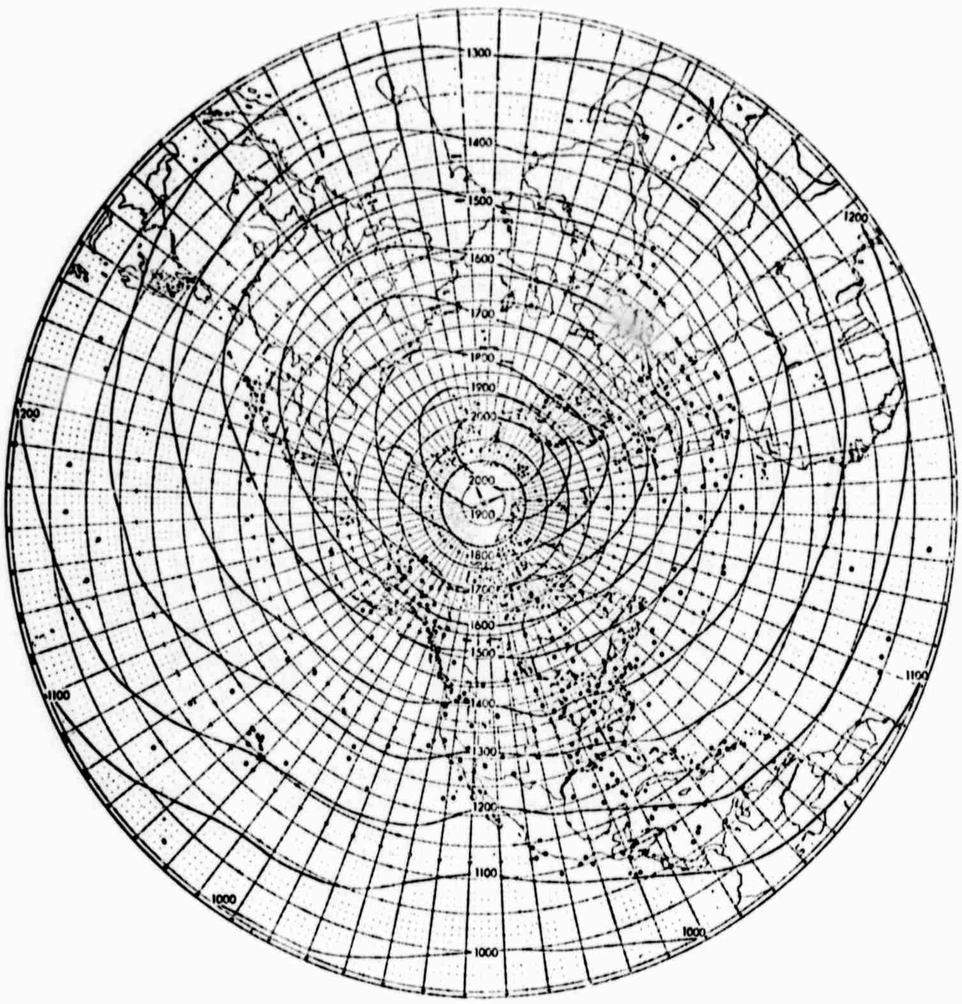


Figure 3: Arrival time of the wave returning to the northern hemisphere after going through the antipodes. (from Wexler and Hass)

atmospheric parameters which are not observed by the world wide meteorological network? If we knew the meteorological parameters how accurately could we estimate the source strength and location?

In theoretical work there seems to be a principle of compounding complexity. If one attempts to enlarge a theory to include a more complicated model then the new complication interacts with all the old complications to create a theory which is too unwieldy to attempt to program. Our approach in this matter will be to throw out some of the complexities of the theory developed by Pfeffer and Zarichney, Press and Harkrider, Pierce, Tolstoy, Claerbout, and others in the hope of being able to include the horizontal atmospheric variations responsible for figures 1-3. With luck what we throw out should be less important than what we include and the final result should be programmable with reasonable effort. We begin by throwing out the altitude variation of temperature and wind. These will be replaced by some kind of average. The average would probably be weighted according to the energy density of the so-called Lamb wave.
In a homogeneous constant temperature atmosphere this is an exponential with a scale height of 15 to 30 kilometers. From these assumptions we may derive a scalar wave equation in two dimensions, that is, on the earth's surface. At this point we could in concept solve the equation by finite differences on a grid. Except for the spherical geometry the actual calculation would not differ a great deal from the seismological calculations of David M. Boore in his recent Ph.D thesis at MIT. In practice a 15 minute period wave sampled

at 10 points per wavelength would require a megaword computer memory to represent the earth. Consideration of concepts of numerical holography indicates that about three orders of magnitude of computational simplification is possible. The full blown two dimensional wave equation has the capability of describing a superposition of many waves each traveling in an arbitrary compass direction. As the data shows we are dealing with merely a single outgoing quasi-circular wave front. The full generality of the two dimensional wave equation is not required and we are at liberty to seek a simpler controling equation. From a ray point of view we may say that the atmospheric irregularity is sufficient to cause rays to bend and perhaps cross over one another but any reflections set up by the irregularity may be neglected. Thus the situation is even simpler than reflection seismology, a field where similar concepts have been applied (Claerbout, 1970, Coarse grid calculations of waves in inhomogeneous media with application to delineation of complicated seismic structure, Geophysics, v. 35, n. 2 or 3 and Claerbout, 1970, Toward a unified theory of reflector mapping, Geophysics, in press). Physically a very natural description is to start at the source and extrapolate the disturbance out around the earth as many times around the earth as it can be observed. Mathematically we must consider a single frequency at a time. Mathematically speaking the total pressure disturbance is periodic with distance from the source, the period being equal to the earth's circumference. What we really need is an equation governing the out-going wave, not the scalar Helmholtz

equation which governs the total pressure at a single frequency where "total" means the sum of all the waves regardless of how many times they have gone around the earth. After a wave goes through the antipodes it returns toward the source. We intend to specialize the monochromatic scalar wave equation in such a way as to eliminate all of the waves which propagate from the antipodes back to the source. In other words we will derive an equation which is first order in $\partial/\partial\theta$ where θ is the distance from the source instead of the wave equation which contains $\partial^2/\partial\theta^2$. This equation will be unable to represent waves which backscatter from atmospheric inhomgeneity or waves which propagate more than one half time around the earth. This equation does not have periodic boundary conditions but is an initial value problem in θ.

Before going to spherical geometry we can more simply illustrate the method in cartesian coordinates. There one wishes to restrict the wave equation to waves with ray compnents in say the plus z direction rejecting those in the minus z direction. Let ω be frequency, c be velocity, and p be pressure. Then the scalar wave equation in material of slowly variable properties is well known to reduce to

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2} + \frac{\omega^2}{c^2} \right) p = 0 \qquad (1)$$

A differential operator operating on pressure p is represented in numerical work by a matrix operating on a vector p where the vector is made up of pressure sampled at various spatial positions. The matrix corresponding to a first derivative looks like, say

$$\frac{\partial}{\partial z}\, p \sim \frac{1}{\Delta z}\begin{bmatrix} 1 & -1 & & & & & \\ & 1 & -1 & & \text{zeros} & & \\ & & 1 & -1 & & & \\ & & & & 0 & & \\ & & & & & 0 & \\ & & & & & & 0 \\ & \text{zeros} & & & & & \end{bmatrix}\begin{bmatrix} p(z) \\ p(z+\Delta z) \\ p(z+2\Delta z) \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} \tag{2}$$

In mumerical work one often asks the matrix to be as large as possible so that the end effects may be pushed off to infinity. Then the matrix corresponding to $\partial^2/\partial z^2$ is merely the square of the matrix corresponding to $\partial/\partial z$. Let us rearrange the factors in the wave equation and take a square root.

$$\frac{\partial^2}{\partial z^2} = -\left(\frac{\omega^2}{c^2} + \frac{\partial^2}{\partial x^2}\right) \tag{3}$$

$$\frac{\partial}{\partial z} = \pm\, i\sqrt{\frac{\omega^2}{c^2} + \frac{\partial^2}{\partial x^2}} \tag{4}$$

The square root of a differential operator may be understood in terms of the square root of a matrix. A matrix A is the square root of another matrix B if $A^2 = B$. Before describing a systematic method of finding the square root operator we indicate why we want it. Equation (4) is a partial differential equation which is first order in z. Thus there is only one independent solution. Depending on the choice of sign of i it is a wave with ray component in the $+z$ direction or the $-z$ direction. In fact the meaning which we wish to impart to the positive square root of the differential operator is

that we will have the same solutions as the wave equation except for those going in a direction which has a component in the negative z-direction. In the customary approach to holography one finds that $\exp(i\omega(t-r/c))/r$ is the solution to the scalar wave equation. The radius $r = (x^2 + z^2)^{1/2}$ is defined by a square root. The choice of sign of the root separates incoming from outgoing waves. Now rather than solve the wave equation and then separate the solutions into outgoing and incoming waves we are trying to write an equation which has only the outgoing waves as a solution. If we achieve this we have converted a boundary value problem into an initial value problem and reduced the calculation accordingly. To reassure the reader that equation (4) is indeed consistant with the wave equation (3) one may differentiate (4) with respect to z

$$\frac{\partial^2}{\partial z^2} = \pm i \sqrt{\frac{\omega^2}{c^2} + \frac{\partial^2}{\partial x^2}}\ \frac{\partial}{\partial z} \tag{5}$$

and substitute (4) into (5) getting the wave equation

$$\frac{\partial^2}{\partial z^2} = i\sqrt{\qquad}\ \ i\sqrt{\qquad}$$

$$= -\frac{\omega^2}{c^2} - \frac{\partial^2}{\partial x^2}$$

The square root of any non-defective matrix can always be defined in an unambiguous fashion. Take the matrix A to be written in diagonal form $A = P\Lambda P^{-1}$ where Λ is a diagonal matrix of eigenvalues and P and P^{-1} contain column and row eigenvectors. Then

the square root of A is simply $A^{1/2} = P \Lambda^{1/2} P^{-1}$ as may readily be verified by substitution. The matrix $\Lambda^{1/2}$ is created from Λ simply by taking the square root of each of the diagonal elements of Λ. There is always a choice of sign in a square root. Choosing all plus signs amounts to choosing all waves in one direction. Choosing all minus signs amounts to choosing all waves in the other direction. Because of this all one may say that it is conceptually clear how $(\omega^2/c^2 + \partial^2/\partial x^2)^{1/2}$ has an unambiguous definition in terms of matrices regardless of space variations in velocity c. This definition is too awkward for computational purposes. A useful approximation if the x-variation of velocity c has small second derivative is given by the binomial theorem, the first two terms of which are given by:

$$(\omega^2/c^2 + \partial^2/\partial x^2)^{1/2} \approx \omega/c + (c/(2\omega))\, \partial^2/\partial x^2$$

Other more accurate approximations may be developed. A more rigorous derivation with computational details is given by Claerbout (1970).

Next we will express these ideas on the sphere. The monochromatic scalar wave equation is

$$(\nabla^2 + \omega^2/c^2)\, p = 0$$

On the surface of a sphere the operators are

$$\frac{1}{r^2 \sin^2\theta} \left[\left(\sin\theta \frac{\partial}{\partial\theta}\right) \left(\sin\theta \frac{\partial}{\partial\theta}\right) + \frac{\partial^2}{\partial\phi^2} \right] + \omega^2/c^2 = 0$$

rearranging and taking the square root as before we get

$$\sin\theta \frac{\partial}{\partial\theta} = i((\omega r \sin\theta/c)^2 + \partial^2/\partial\phi^2)^{1/2} \qquad (6)$$

The square root of the differential operator may be defined as before. One starts the calculation at some $\theta > 0$ by means of an analytic solution for the Lamb mode. The analytic solution may be determined by the method of Press and Harkrider. Then by utilizing some approximation to (6) one could extend the solution in the direction of the antipodes. Because the velocity c may be a realistically complicated function of space the wave is expected to be a mess as it approaches the antipode. Another factor disturbing perfect focus will be the influence of winds. We may avoid a long winded derivation and get a first order wind correction by the following consideration: The effect of a constant velocity wind on a flat earth is exactly the same as a windless earth with a moving coordinate frame. The effect is that an observer not moving at the air speed sees a Doppler shifted frequency. Let ω represent the frequency seen in the earth fixed coordinate frame and Ω represent the frequency seen in the no-wind coordinate frame. It is clear that the extension of (6) to include wind is

$$\sin\theta \frac{\partial}{\partial\theta} = i\,((\Omega r \sin\theta/c)^2 + \partial^2/\partial\phi^2)^{1/2} \qquad (7)$$

By simple geometrical considerations the two frequencies are related by

$$\Omega = \omega - \vec{k}\cdot\vec{v} \qquad (8)$$

where $\vec{k}$ is the wave number vector of a ray and $\vec{v}$ is the wind

velocity vector. The calculation indicated by (7) makes no provision for definition of a wave number vector $\vec{k}$ however to first order it is merely a vector directed away from the explosion of magnitude ω/c. As the wind and temperature mess up the expanding wave more and more so that the outgoing wave represents a wider and wider beam a more refined expression than (7) may be required. In any event (7) is inadequate to the task of carrying the wave through the antipode.

We have not yet conceived of a clean and neat procedure for carrying the wave through the antipodal region. We have a manageable, though messy solution. It depends upon splitting the collapsing wave into several azimuthal zones, transforming to cartesian coordinates, propagating each zone through the irregular focus, and then transforming back to spherical coordinates. We find this unsatisfying in a practical way but philosophically it encourages us to beleive that there does exist a good procedure of getting through an irregular antipode and we should be able to work it out.

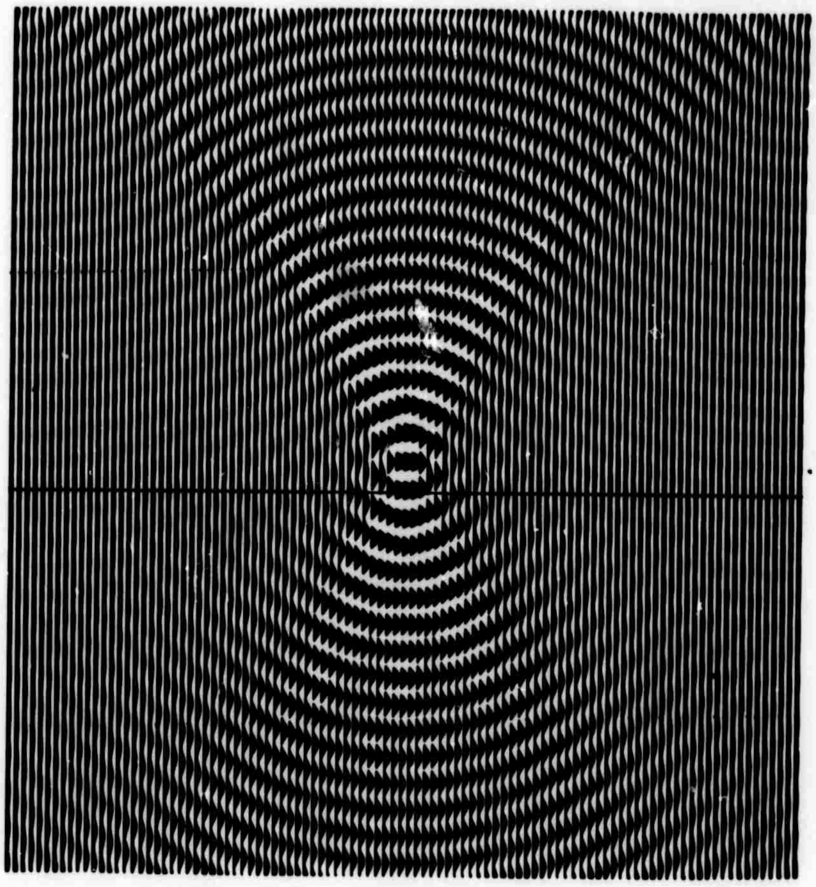


Figure 4 shows a sector of a wave front going through antipodes (focus) in the cartesian approximation. The waves were calculated numerically although an analytic solution was possible in this case. Sparsity of data prevented a calculation based on observations.

III. DATA

A. Description

1. Stanford data and meteorological influences

The records are organized on a daily basis (from 0:00 AM to 12:00 PM). The 7 records corresponding to the data of a week (in the order of Sunday through Saturday) are collected in a single sheet. The size reduced photo copies are shown in Fig.6. through Fig.13.

The records showed daily surface atmospheric pressure fluctuations with relatively high frequencies in the afternoon. In the period of 6/1 to 10/18/1969, a drift in the mean pressure was observed daily from 8:00 AM to 8:00 PM This drift was due to afternoon heating of the instrument. From November on, Dr Theodore Madden's bandpass filter (see section III. B-3) was successfully incorporated in our system. The high frequency fluctuations and the drift in the mean pressure have been removed.

Interesting events were:

1) It was locally quiet for at least two weeks, but at 11:30 PM 6/15/1969, a rather high amplitude signal (about a millibar) arrived. It lasted for an hour and it looked like a

dispersed wave at the beginning, but not so near the end. The largest period was about 10 minutes.

2) 7/13/1969 2:15-9:00 AM

A long period signal came, its amplitude gradually increased and then decreased.

3) 7/141969 3:00 PM

The amplitude suddenly increased twice while the frequencies were as high as usual. It lasted for four hours. The same thing happened at 3:30 PM 7/24/1969 and at 4:30 PM 8/3/69. The possible cause of these events was the 'sea breeze'.

4) Starting at 3:30 AM 9/29/1969, a series of large amplitude waves arrived. The weather was normal and quiet for about three months. At first, we misunderstood it as a nuclear explosion. However, a normal dispersed signal which lasted for 30 minutes was found at 11:05 AM and this was now believed to be a nuclear explosion from Nop Nor (lat:40 degrees N, long: 90 degrees E) in north west China. This event was reported in newspapers. A cold weather front with high altitude trough existed some 1500 miles off shore.

5) A long period (about 8 minutes in average) and big amplitude (about a millibar) signal started at 11:15 PM 10/26/1969 and ended at 5:15 AM 10/27/1969. We believe that was the pass-

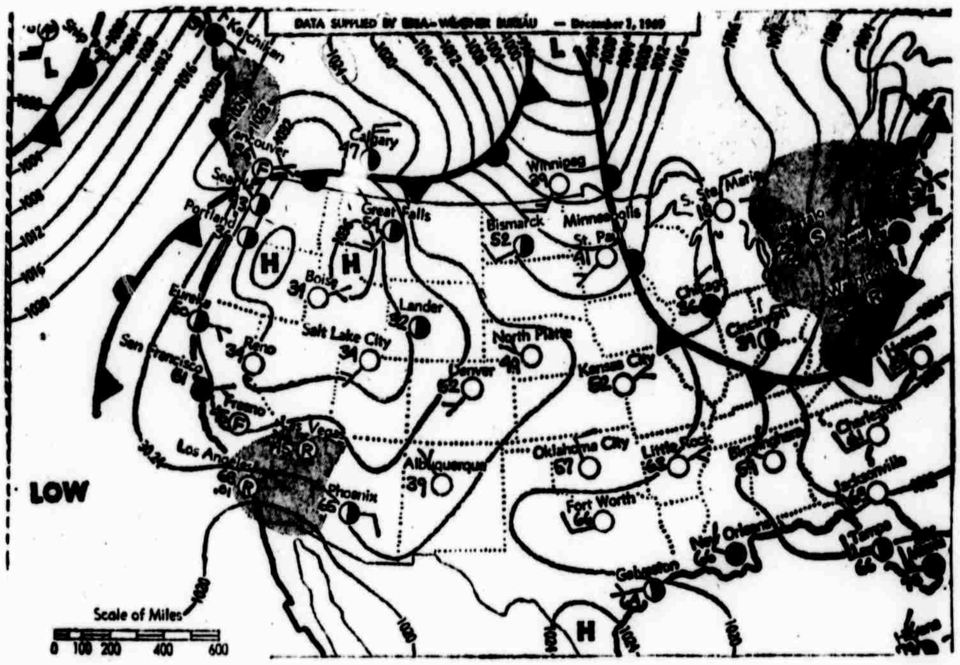
ing of the cold front.

6) At 7:45 12/2/1969, a fantastic large amplitude signal suddenly appeared, it continued for 3 hours and gradually died out. There was a cold front across north western America. The high altitude low pressure core existed 200 miles in the west. The weather map and the pressure record are shown in Fig.5.

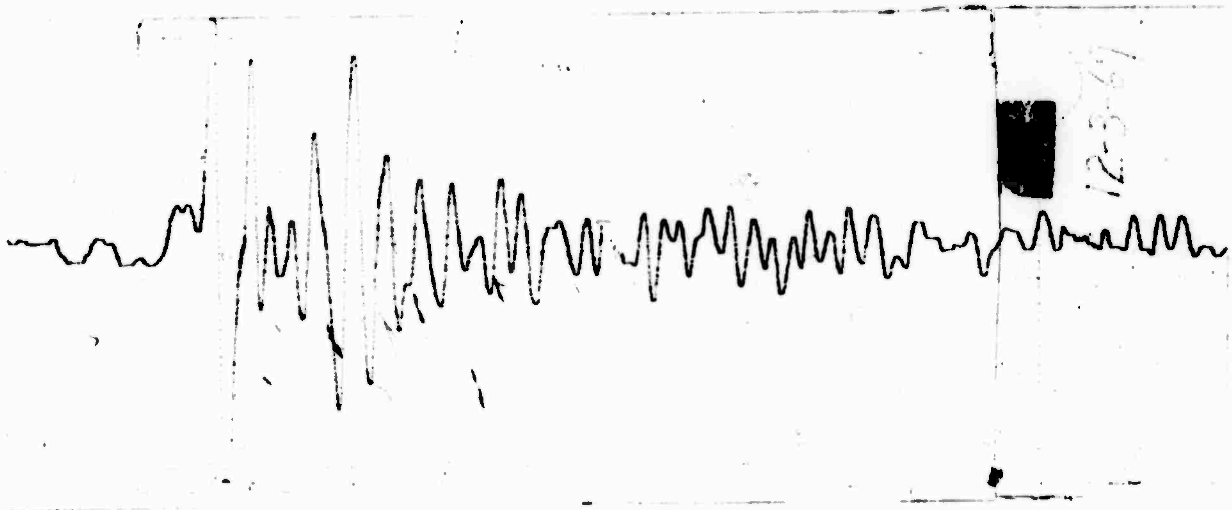
7) 1/23/1970 - 2/16/1970
The raining days have generally high frequencies and large amplitudes in the pressure records.

8) 3/7/1970
The solar eclipse occurred today. The path of the total eclipse was from the Pacific to the North Atlantic, through Mexico, eastern edges of U.S., Nova Scotia, and Newfound. As a great shadow swept the earth, the temperature dropped suddenly the effects on the acoustic-gravity waves should be seen at Stanford about 4:00 PM today, but from the record, nothing special was found.

9) 3/10/1970 7:40 PM - 3/11/1970 7:30 AM
There were long period waves with occasional high amplitude signals. A sinusoidal wave started at 6:08 AM 3/11/1970 and lasted for an hour.



a) The surface weather map (8:00 PM 12/1/1969).



b) The surface pressure record at Stanford. (7:00 PM 12/2/ 1969 - 1:00 AM 12/3/1969)

Fig.5. The weather map and the surface pressure record. The possible cause of this event is by the approaching cold front from north west and the high altitude jet stream from south.

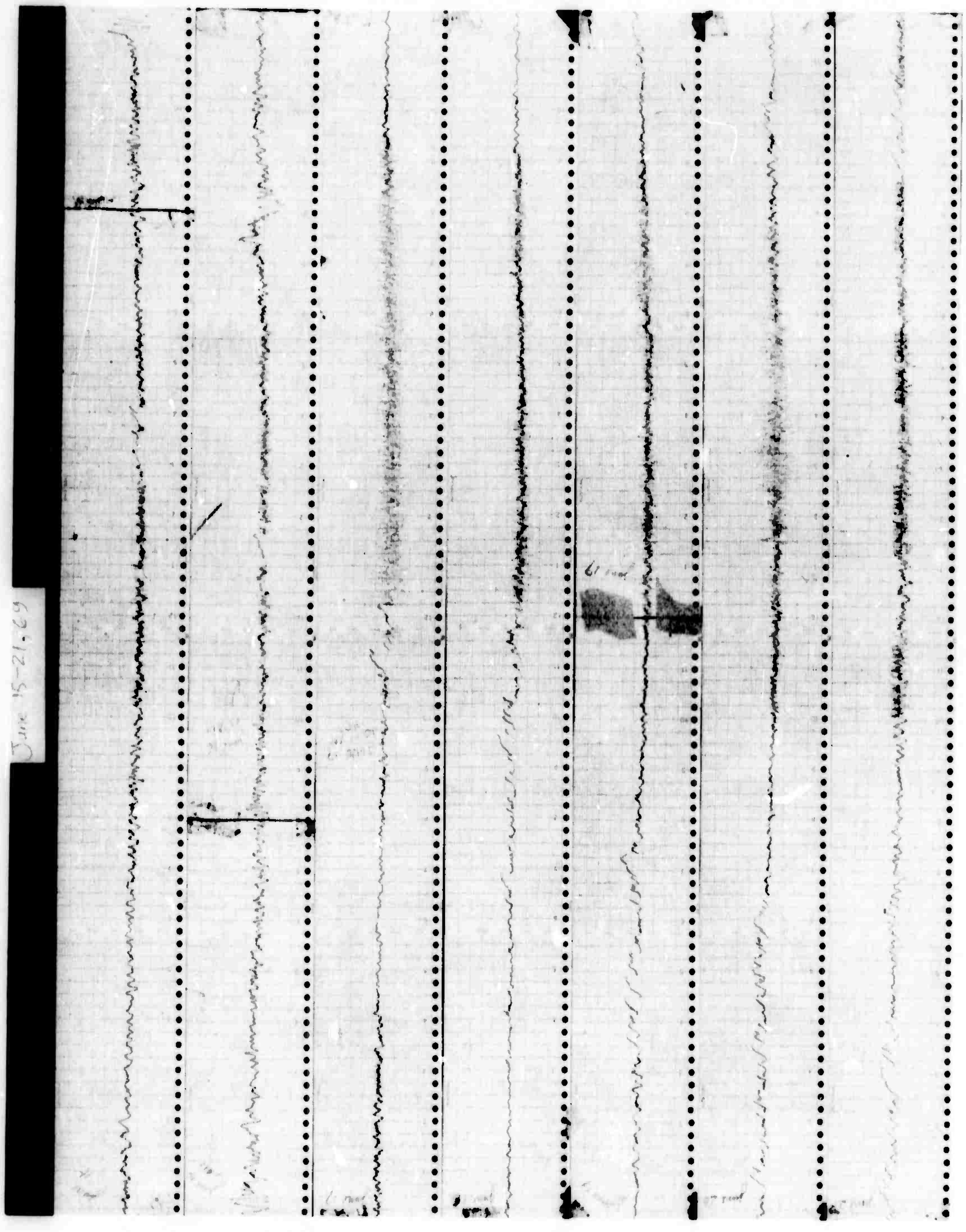


FIG. 6

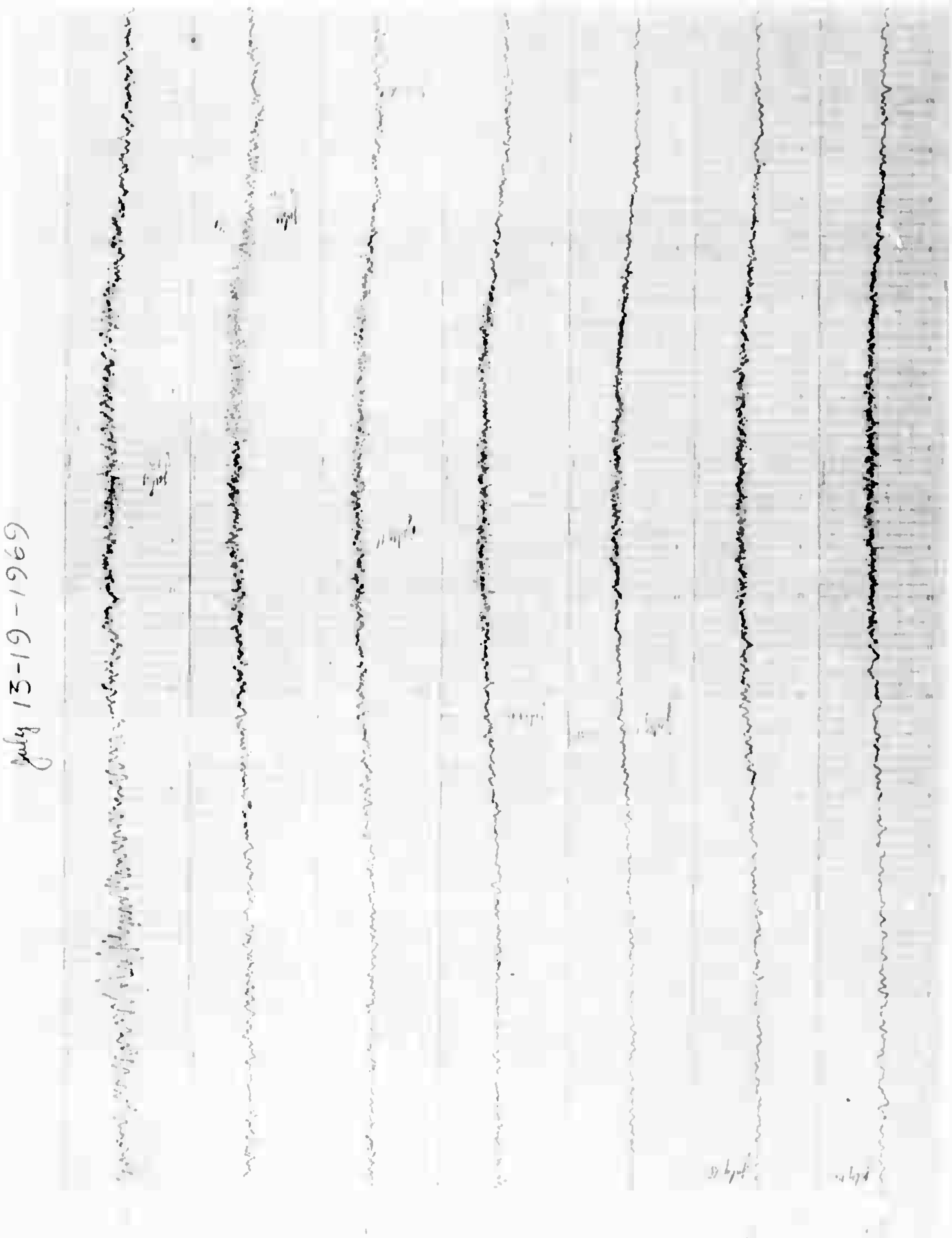


FIG. 7

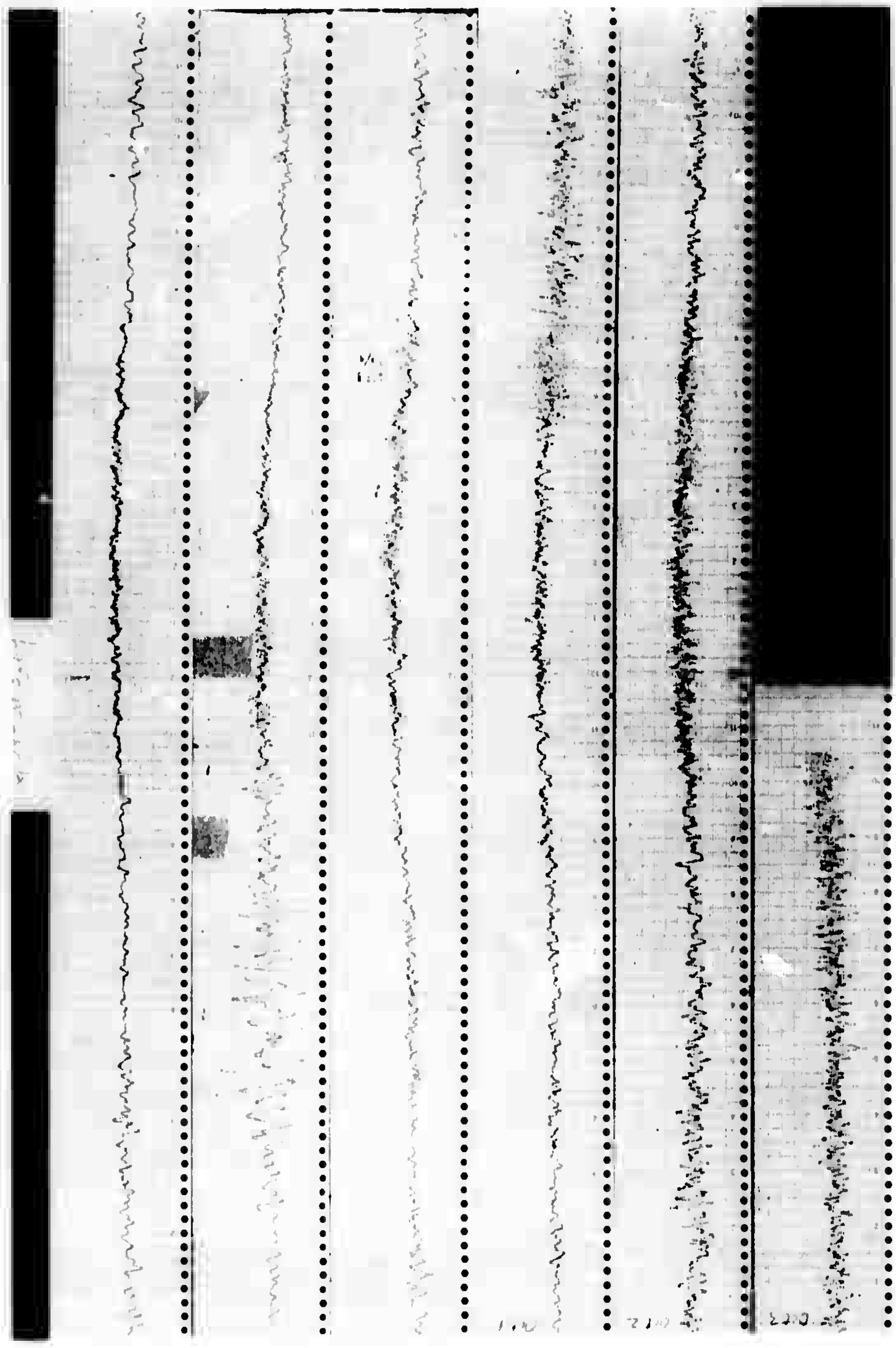


FIG. 8

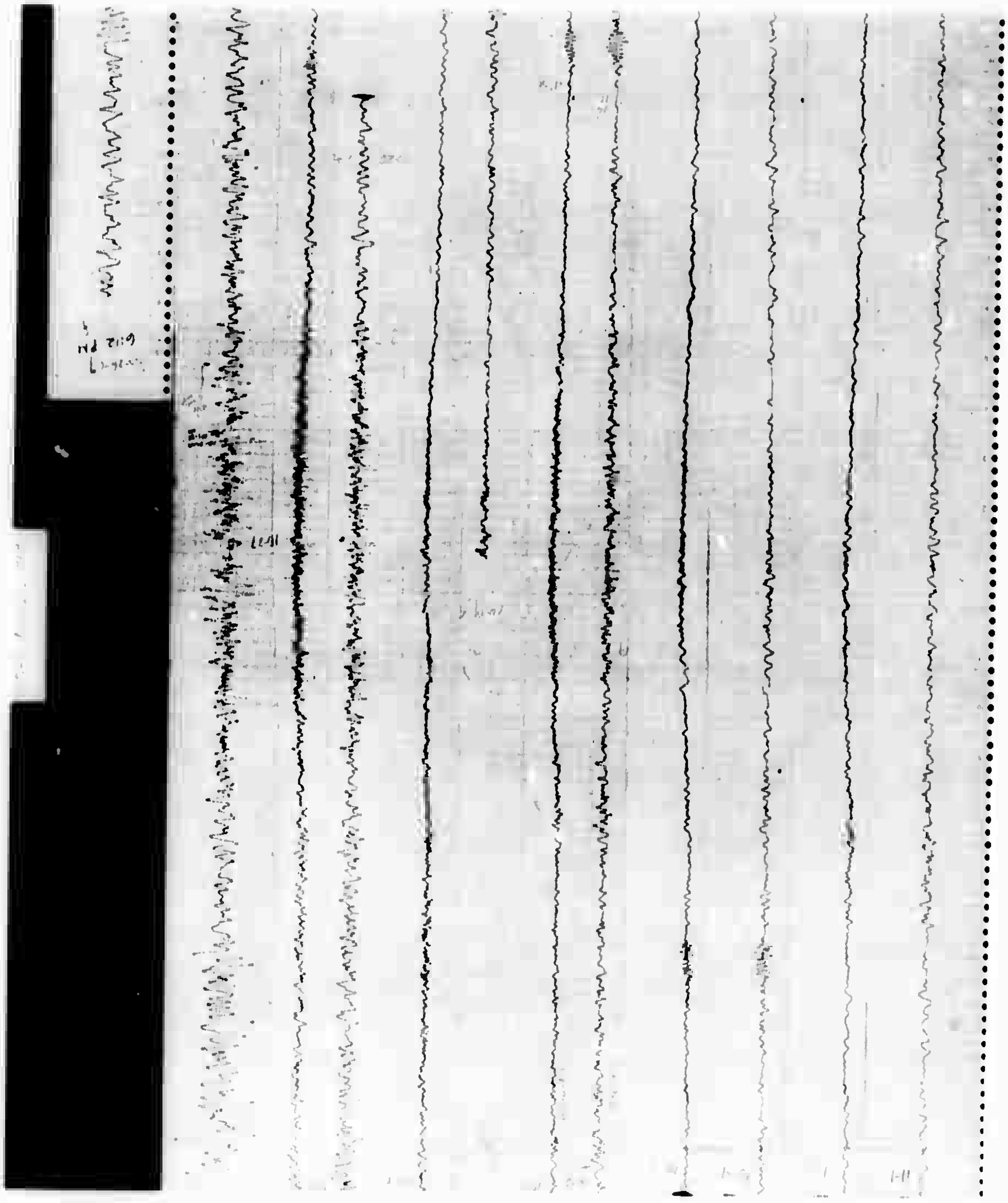


FIG. 9

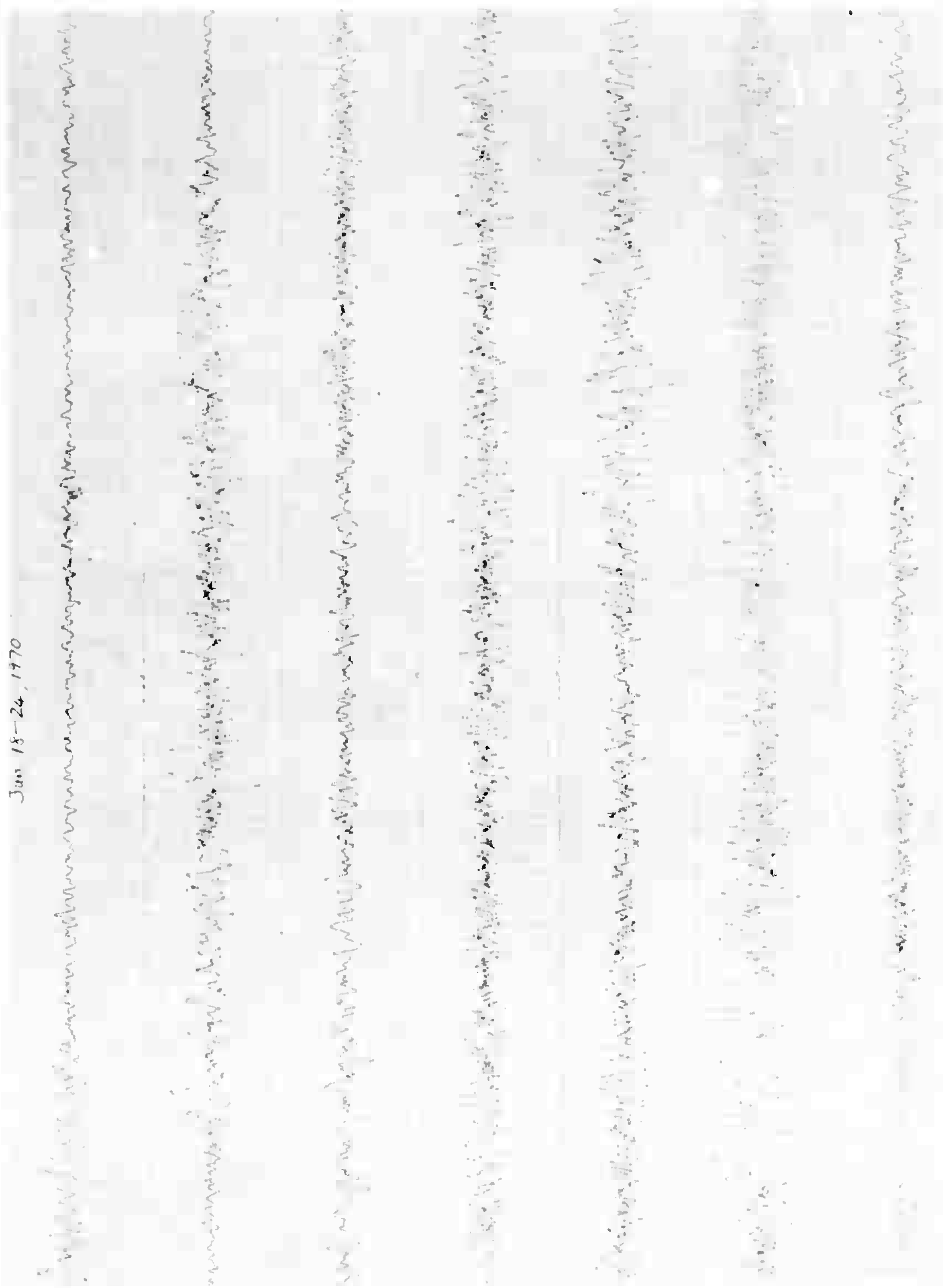


FIG. 10

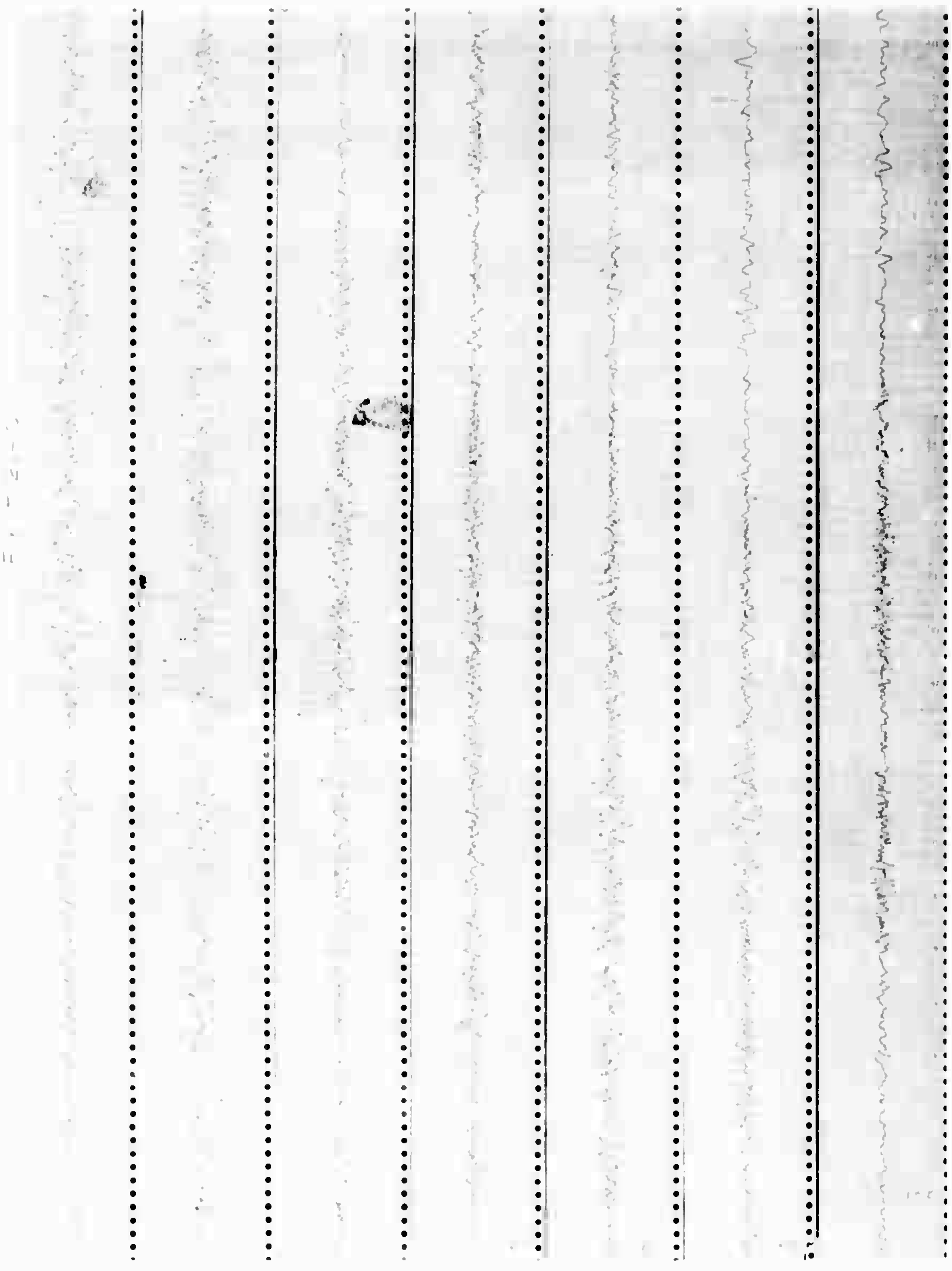


FIG. 11

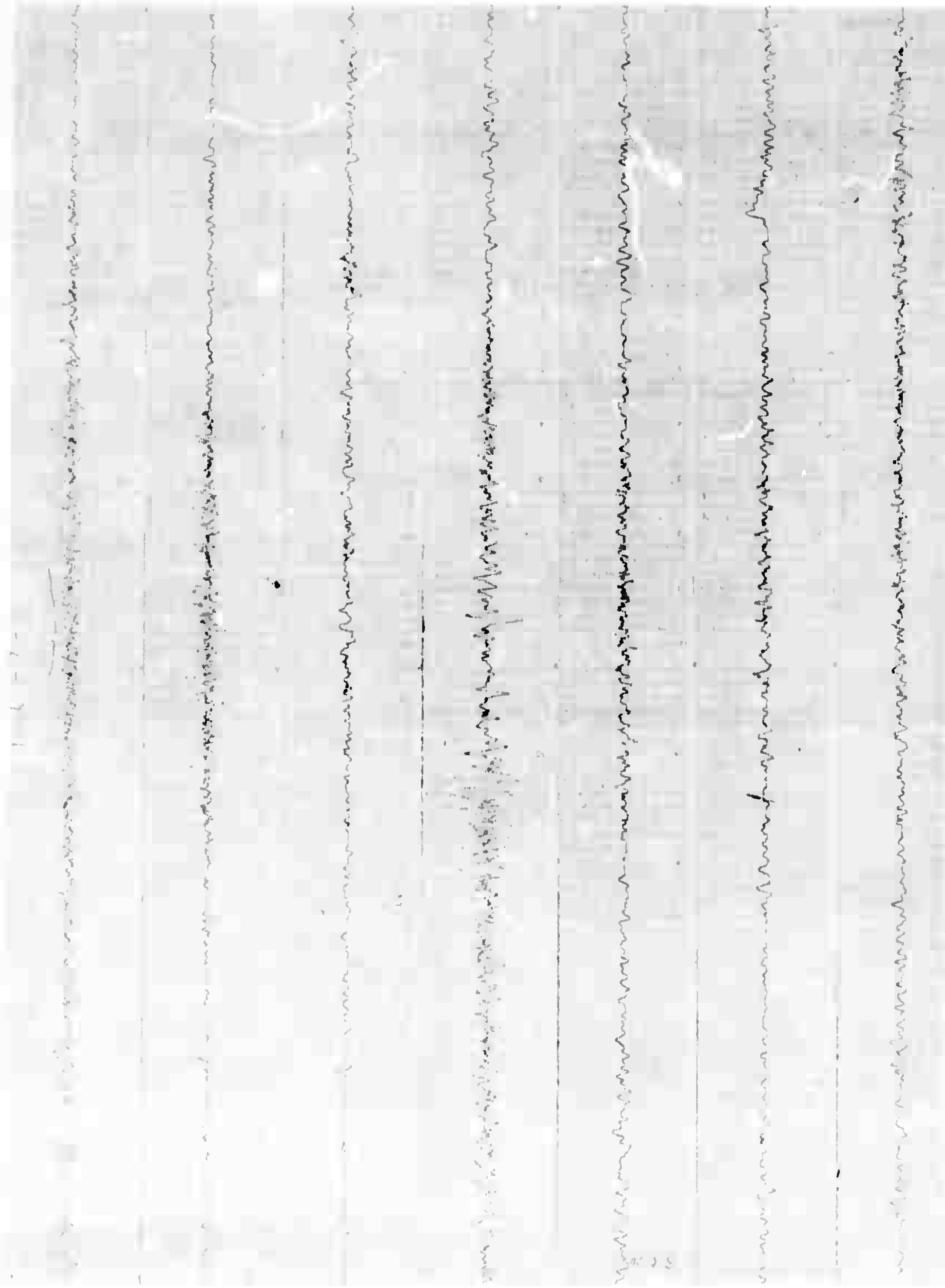


FIG. 12

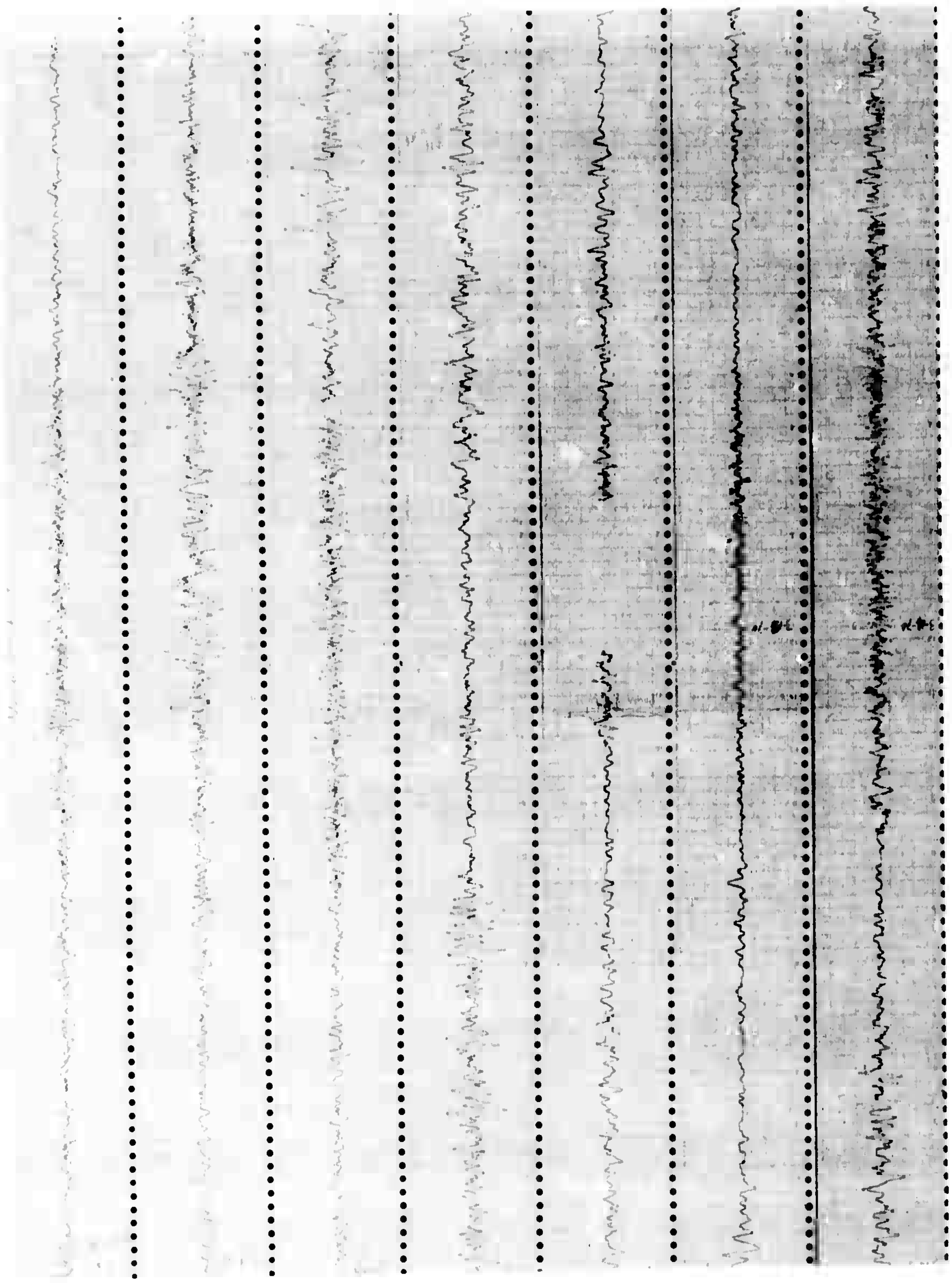


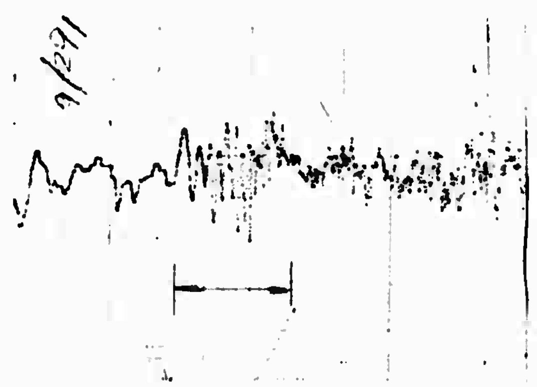
FIG. 13

III. A-2 Telebarom

It was reported in the newspaper that at 8:00 AM EDT 9/28 1969, China exploded a three megaton nuclear device in lower atmosphere. The blast occurred in Lop Nor atomic test area which we take to be at 40 deg. N, 90 deg. E.

The normal dispersed signal arrived here at 11:05 AM 9/29 /1969 (see Fig..14.). The longest period observed was about 8.0 minutes. The event lasted for 40 minutes and the periods were gradually decreasing. If the newspapers were right, the travel time of the acoustic-gravity waves due to this explosion would be 6 hours. The shortest path from north west China to Stanford is via the Arctic. In principle the frequency dispersion in this record should provide us with some information of the average arctic upper atmospheric conditions in autumn. In fact since there are many unknown atmospheric parameters and few observations it is difficult to estimate an atmospheric model from this data alone.

Fig.14. The telebarom of a 1969 Chinese atmospheric nuclear explosion (the arrow shows the event)



III. B. Data Acquisions

1. The Playback Program for LASA Tapes

The LASA records of microbarograph, weather, and long period seismic information are performed on an incremental magnetic tape recorder. The tape format is as follows:

Beginning of the tape | TOD | Frame 1 | Frame 2 |.....
| Frame 120 | record gap | TOD | Frame 1 | Frame 2 .|..
| Frame 120 | EOF gap | End of the tape

The time of the day (TOD), consisting of 2 words and end of file (EOF), are identical to the LASA high rate and low rate words.

Each frame contains data from one sample time and is recorded in the following format:

Frame Word	Site	Function	Frame Word	Site	Function
1	A0	temp.	16	B3	ESSA baro.
2	A0	wind dir.	17	C4	"
3	A0	LTV baro	18	B4	"
4	A0	wind spd	19	C1	"
5	F3	LTV baro	20	C2	"
6	F4	"	21	B2	"
7	A0	"	22	C3	"
8	E4	"	23	D3	"

Frame Word	Site	Function	Frame Word	Site	Function
10	F1	"	25	D1	"
11	E2	"	26	D2	"
12	F2	"	27	F3	LP Z
13	A0	barometer	28	F4	"
14	B1	ESSA bar	29	A0	"
15	A0	"	30	E3	"
31	E4	"	32	E1	"
33	F1	"	34	E2	"
35	F2	"			

Recording is on 7 tracks at 556 bpi. Each record will contain 120 frames of data, each frame containing 35 words. Thus, for 3 characters per data word there are 12,606 characters/record. Each record is then 12,606/556+.75=23.45* inches in length and represents 1 minute of real-time data. The amount of data recorded per tape is then;

hours/tape=tape length (ft)/117.2 ft/hr.

recording for 20 hours will require 2344 ft. of tape, which is about one reel.

The following program 'LASA' with JCL and comments is written for the purpose of reading the tapes.

```
//LASA JOB (J004,315,.9,8,,,,T),'LEE      LU',MSGLEVEL=1
//STEP1 EXEC FORTHCLG
//FORT.SYSIN DD *
C     THIS PROGRAM IS TO READ THE LASA TAPES
C
      REAL*8 DUNCE
      LOGICAL*1 INP(12620)
      EQUIVALENCE(INP(1),DUNCE)
      INTEGER*2 X(3,4202),Y(120,35),ISIGN,FRAME,INT(8,3,2),TOD(10)
C     THE NUMBER OF THE START AND THE END OF THE RECORDS TO BE READ
C     FROM THE PROGRAM
C
      DATA NRECF/1/,NRECL/2/
   10 FORMAT(36Z2)
   20 FORMAT(1X,18I7)
   30 FORMAT(1X,3I1,':',2I1,':',2I1,':',2I1,'.',I1)
   50 FORMAT('1')
      DO 4 KK=NRECF,NRECL
      CALL NOERRD(INP,L,I)
      IF(KK.LT.NRECF) GO TO 4
      IF(KK.GT.NRECL) STOP
C     3 CHARACTERS FORM A WORD
C
      DO 5 I=1,4202
      LL=(I-1)*3
C     LOOK FOR THE TIME OF DAY IN THE BEGINNING OF THE TAPE
C
      DO 5 J=1,3
    5 X(J,I)=INP(LL+J)
      DO 6 J=1,2
      DO 6 K=1,3
      LL=256
      DO 7 L=1,7
      LL=LL/2
      INT(L,K,J)=X(K,J)/LL
    7 IF(INT(L,K,J).EQ.1) X(K,J)=X(K.J)-LL
    6 INT(L,K,J)=X(K,J)
      TOD(1)=INT(3,1,2)*2+INT(4,1,2)
      TOD(2)=INT(5,1,2)*8+INT(6,1,2)*4+INT(7,1,2)*2+INT(8,1,2)
      TOD(3)=INT(3,2,2)*8+INT(4,2,2)*4+INT(5,2,2)*2+INT(6,2,2)
      TOD(4)=INT(8,2,2)*2+INT(3,3,2)
      TOD(5)=INT(4,3,2)*8+INT(5,3,2)*4+INT(6,3,2)*2+INT(7,3,2)
      TOD(6)=INT(3,1,1)*4+INT(4,1,1)*2+INT(5,1,1)
```

```
C     LOOK FOR THE DATA IN EACH FRAME
C
      DO 1 J=1,120
      JBOT=(J-1)*35+7
      JTOP=JBOT+34
      FRAME=0
      DO 1 K=JBOT,JTOP
      FRAME=FRAME+1
      ISIGN=1
      IF(X(1,K).GT.3)ISIGN=-1
      IF(ISIGN.EQ.-1) GO TO 2
      Y(J,FRAME)=X(1,K)*4096+X(2,K)*64+X(3,K)
      GO TO 1
    2 Y(J,FRAME)=(X(1,K)-60)*4096+X(2,K)*64+X(3,K)-16384
    1 CONTINUE
      WRITE(6,50)
      WRITE(6,30)(TOD(I),I=1,10)
      WRITE(6,20)((Y(I,FRAME),FRAME=1,35,2),I=1,120)
    4 CONTINUE
      STOP
      END
/*
//GO.TWO DD DISP=(OLD,KEEP),VOLUME=SER=LAMA,LABEL=(,BLP),UNIT=TAPE7,  X
//              DCB=(DEN=1,RECFM=U,BLKSIZE=32000)
/*
```

III. B-2 The play back procedures for Stanford A/D tapes

The daily digitized pressure fluctuations are recorded on the 7 track tapes by our digital data acquision system. The format of the tapes is:

Beginning of the tape | record 1 | record gap | record 2 |....
| record N | EOF gap | record 1 | record gap | record 2|......
| EOF gap | end of the tape

The data is in the form of two bytes or 12 bits per word. The 6 bits in the first byte together with the first 4 bits of the second byte form the numerical value of a word. The last two bits in the second byte of the word are called the 'u' bit and the 'm' bit respectively. The 'u' bit has the value 1 and 0 alternately on every other word, the 'm' bit has the value 1 if the data comes from analog channel 1 and has the value 0 otherwise. The relation among the hexadecimal, the decimal data words and voltage of of the output from microbarograph is shown in the example below:

Hex	U	M	Decimal	Volts
0000	0	0	0	-10.00
1E2A	1	0	490	-0.43
1E2B	1	1	490	-0.43
2000	0	0	512	0.00
202A	1	0	523	0.22
202B	1	1	523	0.22
3F3C	0	0	1023	10.00

The end of file gap (EOF gap) can be written arbitarily on the tape by pressing the 'file gap' button on our system, usually we write the end of file gap once a day.

The multiplexor has 8 channels. So far only the first channel has been used for the output from the microbarograph. The number of words per record and the speed of recording are changeable. Usually we use 256 words per record and 0.05 data per second.

As an example shown in Fig. 15., good agreement has been found between the microbarograms from the RUSTRAK recorder and from the plot of Stanford A/D tape.

The computer program 'tpread' is written for reading the Stanford A/D tapes. The second program 'baro' is for plotting the microbarograms from the first one. The computer programs with proper JCL are shown in the next few pages.

```
//TPREAD JOB (J004,315,.9,8,,,,T),'LEE       LU',MSGLEVEL=1
//STEP1 EXEC FORTHCLG
//FORT.SYSIN DD *
C     THE FOLLOWING PROGRAM IS TO READ THE STANFORD A/D TAPES
C     USE 'RUN HOLD' TO SAVE DATA ON DESK
C
      REAL*8 DUNCE
      LOGICAL*1  INP(62000)
      EQUIVALENCE  (INP(1),DUNCE)
      INTEGER*2 INT(512),M(512),U(512),G,H
C     DEFINE THE NUMBER OF FILES (NFILES) TO BE READ IN THIS
C     PROGRAM
      NFILES=5
      WRITE(6,2)NFILES
  2   FORMAT(' NFILES=',I3)
      IJ = 1
      NREC = 0
    3 CONTINUE
C     THE BULIt-IN SUBROUTINE NOERRD IS USED HERE TO GET DATA
C     FROM EACH RECORD
   10 CALL NOERRD ( INP, L,   I )
      IF ( I .EQ. 1 ) GO TO 50
      NREC = NREC + 1
      WRITE(6,238)
 238  FORMAT(////)
      IF( I .EQ.-1 ) PRINT 9
    9 FORMAT(      ' READING ERROR ENCOUNTERED IN FOLLOWING RECORD')
      L1=L/2
      WRITE(6,232)NREC,L
 232  FORMAT(' RECORD NO.',I5,I10,' BYTES LONG')
C     CHECK DATA IN HEXADECIMAL FORMAT BY USING THE
C     FOLLOWING WRITE STATEMENT
C     WRITE(6,22)(INP(K),K=1,L)
C  22 FORMAT(1X,32Z2)
      DO 101 K=1,L
 101  INT(K)=INP(K)
      J=1
      K=0
C     LOOK FOR THE DECIMAL DATA
C
 105  DO 102 L=J,256
      K=K+1
      K2=2*K
      H=INT(K2)/4
      G=INT(K2)-H*4
      U(L)=G/2
      M(L)=G-U(L)*2
```

```
      IU=U(L)
      IF(K.EQ.1)GO TO 111
      IF((IU+IJ).NE.1) GO TO 103
 111  JU=U(L)
 102  INT(L)=H+INT(K2-1)*16-512
      GO TO 106
 103  K=K-1
      DO 104 J=L,256
      K=K+1
      K2ADD1=2*K+1
      H=INT(K2ADD1)/4
      G=INT(K2ADD1)-H*4
      U(J)=G/2
      M(J)=G-U(J)*2
      IU=U(J)
      IF((IU+JU).NE.1) GO TC 105
      JU=U(J)
 104  INT(J)=H+INT(K2ADD1-1)*16-512
 106  CONTINUE
      WRITE(6,235)(INT(K),K=1,256)
 235  FORMAT(1X,16I5)
c     check u and m bits by using the following state-
c     ments
c
C     WRITE(6,236)
C 236 FORMAT(/,'       U:')
C     WRITE(6,235) (U(K),K=1,256)
C     WRITE(6,237)
C 237 FORMAT(/,'       M:')
C     WRITE(6,235) (M(K),K=1,256)
      GO TO 3
   50 CONTINUE
      WRITE(6,51) IJ
      NREC = 0
   51 FORMAT('0END OF FILE NO.',I4,/,'1',//)
      IF( IJ .GE. NFILES ) STOP
      IJ = IJ + 1
C     PROGRAM AROUND A BUG IN NOERRD BY MAKING AN EXTRA CALL NOW.
      CALL NOERRD(INP, L,I)
      GO TO 10
      END
/*
//GO.TWO DD DISP=(OLD,KEEP),VOLUME=SER=G009,LABEL=(,BLP),UNIT=TAPE7,    X
//              DCB=(RECFM=U,BLKSIZE=32000)
/*
```

```
//BARO JOB (J004,315,.9,2,,,,T),'LEE LU',MSGLEVEL=1
// EXEC PLOTCLG
//FORT.SYSIN DD *
C     THE FOLLOWING PROGRAM IS TO PLOT THE OUTPUT FROM LASA
C     OR STANFORD A/D TAPES
C
      INTEGER*2 INT(1536)
      REAL*4 RINT(1536)
C     READ DATA FROM OUTPUT OF THE TAPE AND CONVERT TO REAL NUMBERS
C
      READ(5,1) (INT(I), I=1,1536)
      WRITE(6,1) (INT(I), I=1,1536)
    1 FORMAT(16I5)
      DO 2 I=1,1536
      J=INT(I)
    2 RINT(I)=FLOAT(J)
C     WRITE THE TITLE AND PLOT THE TIME SERIES
C
      CALL STRTP1(10)
      CALL SYMBL1(3.,7.,.3,'MICROBARO. 6 RECORDS START AT 10:50 PM 5/12
     */69',46)
      CALL PLOT1(0.,2.5,23)
      CALL TPLOT(1,1536,RINT,1.,8.5,1.,1,1.)
      CALL ENDP1
      STOP
      END
      SUBROUTINE TPLOT(LINES,L,X,FILL,XINCH,YINCH,MEANS,PTDELT)
C     FILL=OVERLAP FACTOR: 1 IS NO OVERLAP,10**6 FOR COMMON AXIS
C     XINCH=LENGTH IN INCHES
C     YINCH=WIDTH IN INCHES
C     |MEANS|=1 FOR MEAN LINES AND MEANS.LT.0 FOR VERTICAL AXIS
C     PTDELT=SEPARATION FROM PRECEEDING PLOT
C     IF FILL IS NEGATIVE THEN PIPS
C     MUST PLACE CALL STRTP1(10) AND ENDP1 BEFORE AND AFTER CALLS RESPEC
      DIMENSION X(L)
      OPT=SIGN(1.,FILL)
      M=ISIGN(1,MEANS)
      MEANS=IABS(MEANS)
      FILL=ABS(FILL)
      DTIN=AMAX1(.01,(XINCH*LINES)/L)
      SIDES=1.
      B=0.
      DO 5 I=1,L
      IF(X(I).LT.0)SIDES=2.
 5    IF(ABS(X(I)).GT.B)B=ABS(X(I))
      DY=FILL*YINCH/(FILL+LINES-1)/SIDES
      DM=SIDES*DY/FILL
      CALL PLOT1(PTDELT,5.,23)
      K=L/LINES
```

```
      SP=YINCH/2.-DY
      DO 3 I=1,LINES
      CALL PLOT1(0.,SP,23)
      IF(M.NE.-1)GO TO 2
      CALL PLOT1(0.,DY,2)
      X1=0.
      IF(SIDES.EQ.2)X1=-DY
      CALL PLOT1(0.,X1,2)
      CALL PLOT1(0.,0.,3)
 2    CONTINUE
      SP=-DM
      Y=X(1+K*(I-1))*DY/B
      Z=0.
      CALL PLOT1(Z,Y,3)
      IF(OPT)8,8,9
 8    CALL PLOT1(Z,0.,2)
 9    CONTINUE
      DO 4 J=2,K
      Y=X(J+K*(I-1))*DY/B
      Z=DTIN+Z
      IF(OPT)7,7,6
 7    CALL PLOT1(Z,0.,2)
      CALL PLOT1(Z,Y,2)
      CALL PLOT1(Z,0.,2)
      GO TO 4
 6    CALL PLOT1(Z,Y,2)
 4    CONTINUE
      Z=Z+DTIN
      IF(MEANS.NE.1)GO TO 3
      CALL PLOT1(Z,0.,3)
      CALL PLOT1(0.,0.,2)
 3    CALL PLOT1(0.,0.,3)
      IF(SIDES.EQ.1.)DY=0.
      DY=-1.*(DY+5.-YINCH/2.)
      XINCH=XINCH-DTIN
      CALL PLOT1(XINCH,DY,23)
      RETURN
      END
/*
//GO.SYSIN  DD  *
(THE DATA FROM TAPES IN THE FORMAT OF 16I5)
/*
```

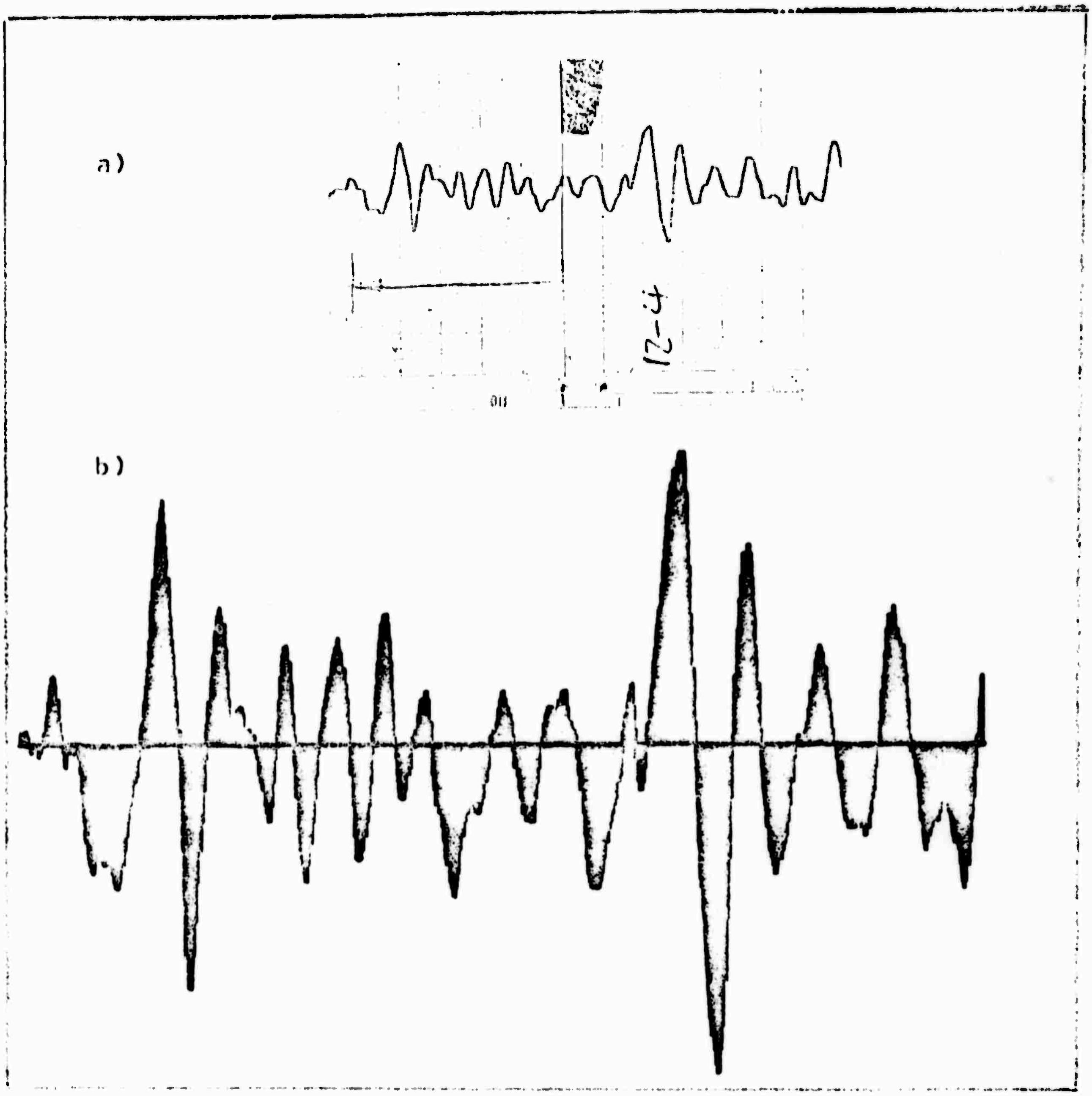


Fig. 15. : Microbarogram (start from 10:44 PM 12/4 to 1:35 AM 12/5/69)

a) The record from RUSTRAK recorder. (1 inch/hour).

b) The plot from Stanford A/D tape. (2 records or 512 words of data in the length of 6 inches, the speed of the recording is 20 seconds/data word).

III. B-3 The Microbarograph Filter

The information of the band-pass filter was provided by Dr. Theodore Madden. The high-pass time constant is 500 sec equivalent to 45 min. cut off which is somewhat longer than the leak cutoff. The low pass is not critical due to the natural fall off of the pressure fluctuations with frequency for periods less than the Brunt Väisälä period.

The circuit diagram of the filter is following:

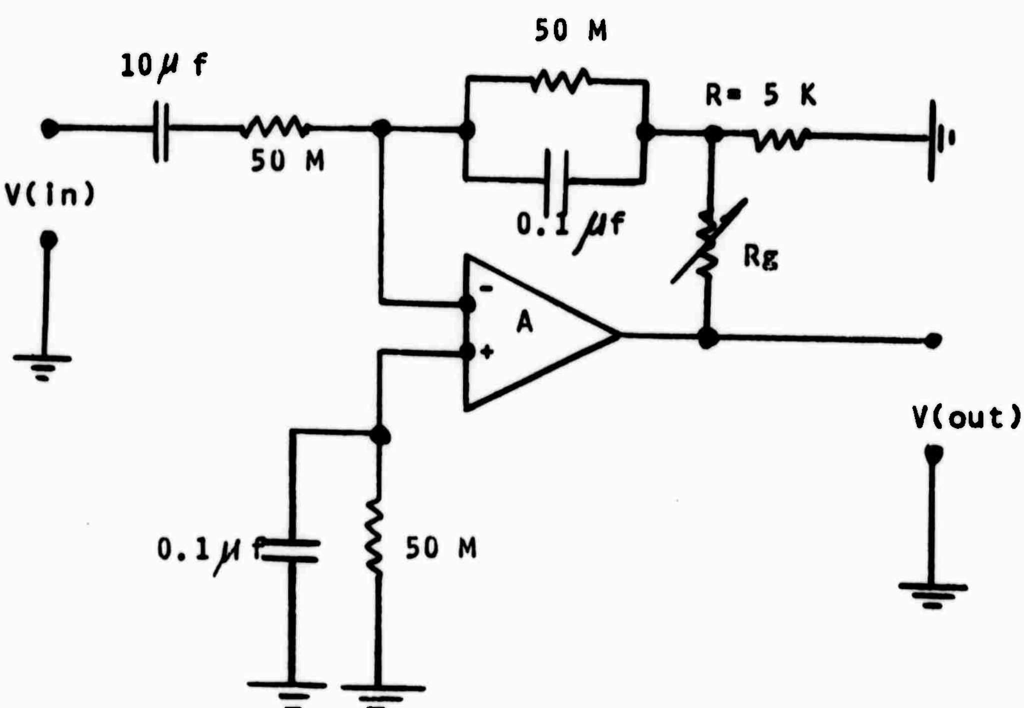


Fig.16. The circuit diagram of the bandpass filter.

The 'A' in Fig.16. is a low current offset and high impedance FET or parametric amplifier. We used the FET operational amplifier Model 141A by ANALOG DEVICES INC., because of the low cost and the low input bias current.

The gain and the pass band are determined by the characteristics of the equation:

V(out)=-((R+Rg)/R)*(Z2/Z1)*V(in)

Where, the gain=(R+Rg)/R, and in our case
Z2/Z1=500.*j*w/((1.+5.*j*w)*(1.+500.*j*w))

The pass band is calculated from two poles in Z2/Z1, ie. the angular frequency is in between 0.2 and 0.002 cps or the period is within the passband of 0.5 to 52.3 minutes. The characteric curve of |Z2/Z1| is shown in Fig.17. An example of the filtered and the unfiltered pressure records are compared in Fig.18. The high frequency fluctuations (>0.2 cps) have been successfully removed.

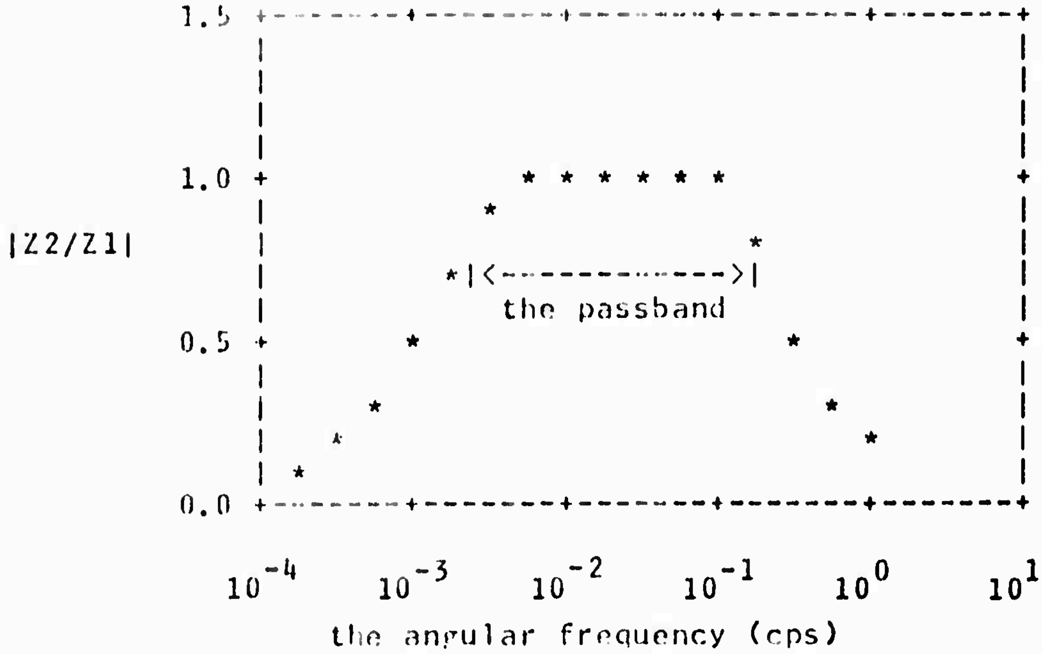


Fig. 17. The characteristic curve of |Z2/Z1|

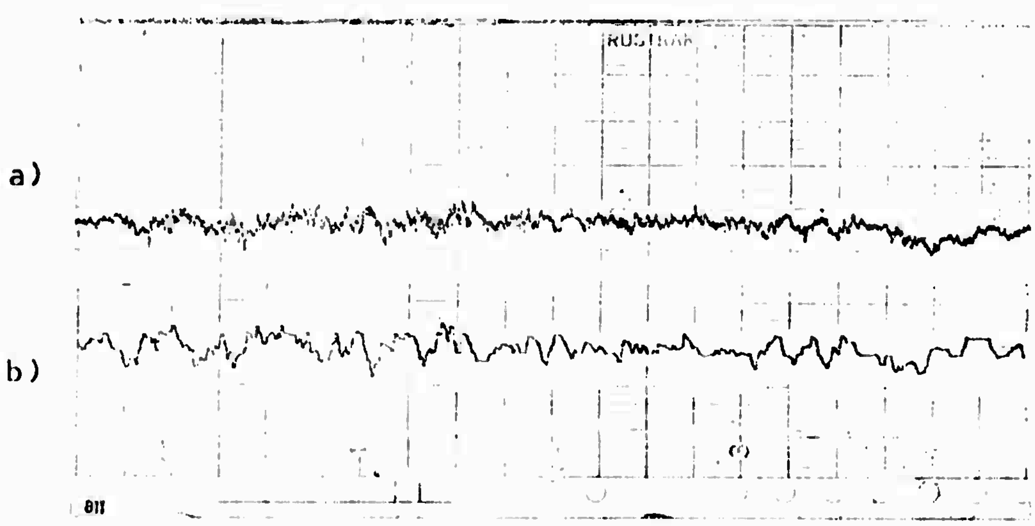


Fig.18. a) The unfiltered microbarogram.

b) The filtered microbarogram.

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13. ABSTRACT

Theoretical work included mathematical-computational simulation of an air wave propagating around the earth. The effect of horizontal variations of wind and temperature was included. These explain the severe defocussing always observed at the antipodes.

Observational work included installation and operation of an LTV-LASA type microbarograph. Regular inspection of the records revealed a nuclear explosion and numerous incompletely understood meteorologic phenomena. Computer programs have been written and documented for reading LASA data tapes and Stanford data tapes.

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